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What Aircrews Should Know About Their Occupational Exposure to Ionizing Radiation

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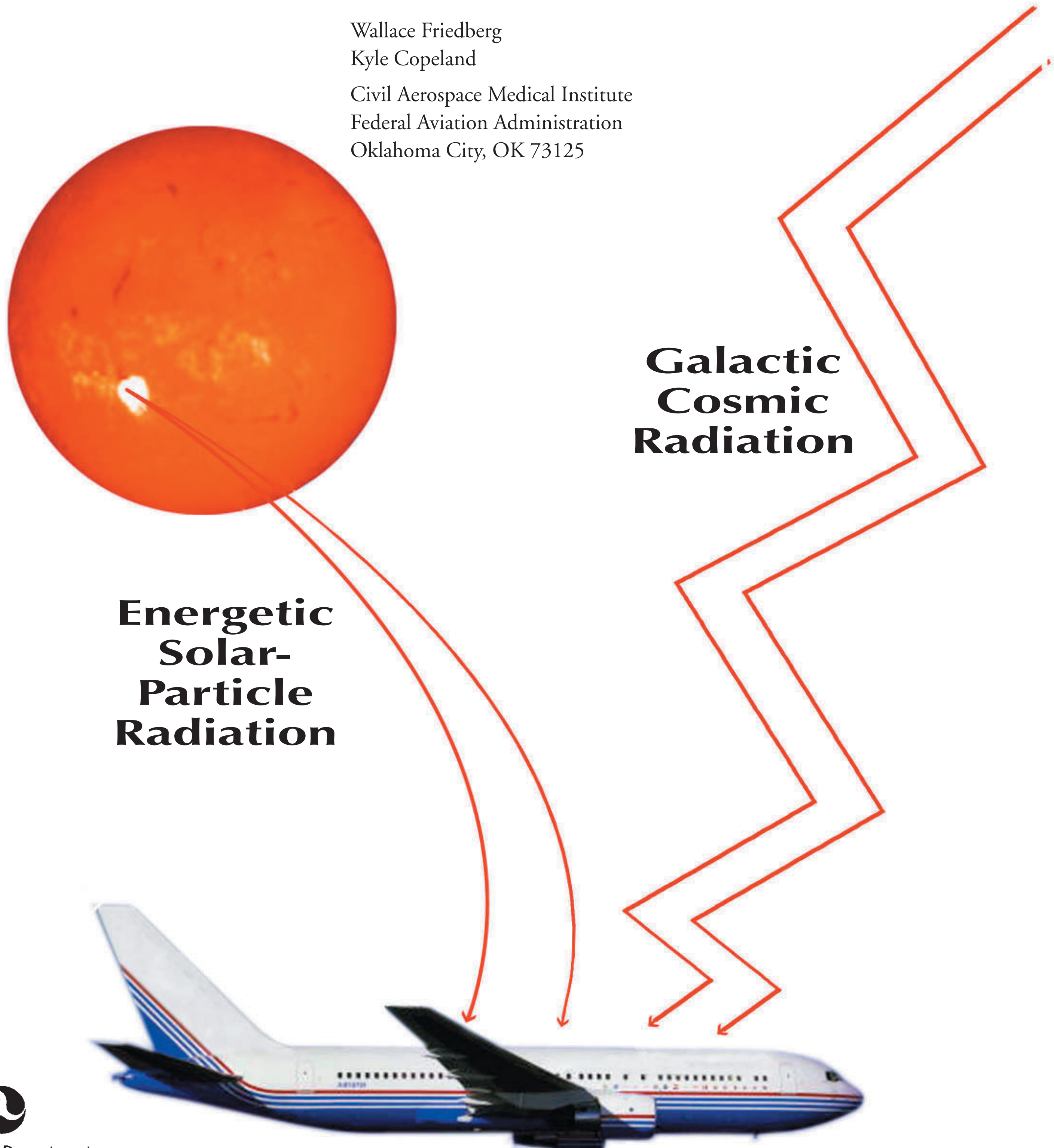

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16. Abstract

Aircrews are occupationally exposed to ionizing radiation, principally from galactic cosmic radiation. A main source of galactic cosmic radiation is believed to be supernovae. On infrequent occasions, the sun contributes to the ionizing radiation received during air travel. Ionizing radiation consists of subatomic particles that, on interacting with an atom, can cause the atom to lose one or more orbital electrons or even break apart its nucleus. Such events occurring in body tissues may lead to health problems. For aircrews, and their children irradiated in utero, the principal health concern is a small increase in the lifetime risk of fatal cancer. For both of these groups, exposure to ionizing radiation also leads to a risk of genetic defects in future generations. The FAA recommends limits for aircrews in their occupational exposure to ionizing radiation and provides computer software for estimating the amount of galactic cosmic radiation received on a flight.

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WHAT AIRCREWS SHOULD KNOW ABOUT THEIR OCCUPATIONAL EXPOSURE TO IONIZING RADIATION

In a Presidential Document, Radiation Protection Guidance to Federal Agencies for Occupational Exposure, 52(17) Fed. Reg. 2822-2834 (1987), it is recommended that individuals who are occupationally exposed to ionizing radiation and managers of these activities, receive instruction on possible health effects associated with such exposure and on basic radiation protection principles.

In 1994, the Federal Aviation Administration (FAA) formally recognized that air carrier aircrews are occupationally exposed to ionizing radiation and recommended that they be informed about their radiation exposure and associated health risks and that they be assisted in making informed decisions with regard to their work environment (1). The following questions and answers address subjects that aircrews should be familiar with concerning their occupational exposure to ionizing radiation.

1. What is ionizing radiation?

Ionizing radiation refers to subatomic particles that on interacting with an atom can directly or indirectly cause the atom to lose an electron or even break apart its nucleus. Such occurrences in body tissues may cause health problems. Examples of ionizing radiation are photons (X-rays and gamma rays), neutrons, protons, electrons, and positrons. Ionizing radiation is a normal part of our environment (Table 1). Substances that emit ionizing radiation are present in every cell in the body. We are exposed to ionizing radiation emanating from the ground and from some building materials. Ionizing radiation is used in some medical procedures, such as X-rays used to detect diseases of the chest and radioisotopes used for detecting and treating cancer. The principal ionizing radiation to which air travelers are exposed is galactic cosmic radiation, a main source of which is believed to be supernovae (exploding stars).

Table 1. Average Annual Doses of Ionizing Radiation From Natural Sources Received by a Member of the Population of the United States (2)

Source	Effective dose, millisieverts (% of total)
GALACTIC COSMIC RADIATION * (Uniform whole-body exposure)	0.27 (9%)
RADIOACTIVE MATERIAL IN THE GROUND (Uniform whole-body exposure)	0.28 (9%)
INHALED RADON (Primarily to bronchial epithelium)	2.0 (68%)
RADIOACTIVE MATERIAL IN BODY TISSUES (Tissue doses vary)	0.40 (14%)
Total from natural sources =	2.95 (100%)

* Includes 0.01 millisievert from air travel.

Outside the earth's atmosphere, galactic cosmic radiation consists mostly of fast-moving protons (hydrogen nuclei) and alpha particles (helium nuclei). On entering the atmosphere, these particles collide with the nuclei of nitrogen, oxygen, and other air atoms, generating additional ionizing radiation particles. The particles that enter the atmosphere and those generated are collectively referred to as galactic cosmic radiation. At aircraft flight altitudes, the dose of galactic cosmic radiation received by air travelers is mainly from neutrons, protons, electrons, positrons, and photons.

Occasionally a disturbance in the sun's atmosphere (solar flare, coronal mass ejection) leads to a surge of radiation particles with sufficient energy to penetrate the earth's magnetic field and enter the atmosphere. The particles from such a solar disturbance interact with air atoms in the same way as galactic cosmic radiation particles. The result is that for varying amounts of time air travelers are exposed to both ionizing radiation from the sun and galactic cosmic radiation.

2. How can an airline minimize the risk of aircraft occupants being exposed to excessive amounts of ionizing radiation from the sun?

A Solar Radiation Alert system has been developed that considerably reduces the risk to air travelers of being exposed to excessive amounts of ionizing radiation following a severe solar disturbance. Accompanying an alert is a message with estimates of radiation levels at altitudes from 20,000 ft to 80,000 ft, at specified high latitudes (map of specified high latitudes on Web site identified below), and a recommended maximum flight altitude at these latitudes.

http://www.cami.jccbi.gov/radiation.html

Solar Radiation Alerts are transmitted worldwide to subscribers of the National Oceanic and Atmospheric Administration's Weather Wire Service. For air-carrier aircraft, the recommended response to a Solar Radiation Alert is to minimize flight time at altitudes that exceed the recommended maximum flight altitude.

3. What else about radiation from the sun is of interest to aircrews?

Ionizing radiation from the sun cannot be avoided by flying only at night. Following a severe solar disturbance, ionizing radiation particles from the sun that reach the earth's atmosphere are soon coming from all directions because of the spreading effect by the interplanetary and earth's magnetic fields. If the ionizing radiation levels on the day and night sides of the earth start out appreciable different, they will be almost the same with 1 hour to a few hours.

Long-distance communications are sometimes disrupted because of increased ionization of the earth's upper atmosphere by X-rays, ultraviolet radiation, or protons from the sun. This can occur in the absence of excessive ionizing radiation levels at flight altitudes.

The Aurora Borealis and Aurora Australis (northern and southern lights) are colorful displays resulting from interaction of charged particles with air in the upper atmosphere. Such displays are not an indication of increased ionizing radiation levels at flight altitudes and do not present a hazard to air travelers.

4. How can aircrew members reduce their occupational exposure to ionizing radiation without working fewer hours?

Fly short flights at low latitudes. Short flights are flown at lower altitudes than long-distance flights, hence there is more radiation shielding during short flights because of the greater amount of air above the aircraft. If two flights are flown at the same altitude for the same length of time, but at different geographic latitudes, less radiation will usually be received on the lower-latitude flight because of the greater amount of radiation shielding provided by the earth's magnetic field. This shielding is maximum near the equator and gradually decreases to zero as one goes north or south (3). For example, during the period January 1958 through December 2002 at an altitude of 30,000 ft, the average galactic cosmic radiation level over Reykjavik, Iceland (64° N, 22° W), was approximately twice that over Lima, Peru (12° S, 77° W).

5. What units are used to express amounts of ionizing radiation exposure?

When considering potential harmful health consequences from exposure to ionizing radiation, radiation dose is usually expressed in terms of effective dose (4). However, if the radiation is to a conceptus (any stage of prenatal development from the fertilized egg to birth), dose is expressed in terms of equivalent dose. The unit of both effective dose and equivalent dose (4) is the sievert, which is a measure of potential harm from ionizing radiation.

1 sievert = 1000 millisieverts
1 millisievert = 1000 microsieverts

The rem is another unit used to express potential harm from ionizing radiation.

100 rem = 1 sievert

6. What are the recommended limits of occupational exposure to ionizing radiation for aircrews?

The FAA recommended limit for an aircrew member is a 5-year average effective dose of 20 millisieverts per year,

Table 2. Effective Dose of Galactic Cosmic Radiation Received on Air Carrier Flights as Calculated with CARI-6

Origin–Destination	Single nonstop one-way flight: Highest altitude, feet in thousands	Air time, hours	Block hours *	Milli-sievert †	Milli-sievert per block hour ‡
1	2	3	4	5	6
Seattle WA - Portland OR	21	0.4	0.6	0.00017	0.0003
Houston TX - Austin TX	20	0.5	0.6	0.00017	0.0003
Miami FL - Tampa FL	24	0.6	0.8	0.00039	0.0005
St. Louis MO - Tulsa OK	35	0.9	1.1	0.00171	0.0016
Tampa FL - St. Louis MO	31	2.0	2.2	0.00471	0.0021
New Orleans LA - San Antonio TX	39	1.2	1.3	0.00327	0.0025
Los Angeles CA - Honolulu HI	35	5.2	5.6	0.0147	0.0026
New York NY - San Juan PR	37	3.0	3.4	0.0101	0.0030
Honolulu HI - Los Angeles CA	40	5.1	5.5	0.0164	0.0030
Los Angeles CA - Tokyo JP	40	11.7	12.0	0.0434	0.0036
Tokyo JP - Los Angeles CA	37	8.8	9.3	0.0334	0.0036
Washington DC - Los Angeles CA	35	4.7	4.9	0.0191	0.0039
New York NY - Chicago IL	39	1.8	2.3	0.00892	0.0039
Lisbon PG - New York NY	39	6.5	6.9	0.0289	0.0042
London UK - Dallas/Ft. Worth TX	39	9.7	10.2	0.0437	0.0043
Seattle WA - Washington DC	37	4.1	4.4	0.0192	0.0044
Dallas/Ft Worth TX - London UK	37	8.5	9.0	0.0396	0.0044
Chicago IL - San Francisco CA	39	3.8	4.3	0.0194	0.0045
Seattle WA - Anchorage AK	35	3.4	3.7	0.0169	0.0046
San Francisco CA - Chicago IL	41	3.8	4.3	0.0207	0.0048
New York NY - Seattle WA	39	4.9	5.6	0.0280	0.0050
London UK - New York NY	37	6.8	7.3	0.0374	0.0051
New York NY - Tokyo JP	43	13.0	13.6	0.0754	0.0055
Tokyo JP - New York NY	41	12.2	12.5	0.0696	0.0056
London UK - Los Angeles CA	39	10.5	11.0	0.0616	0.0056
Chicago IL - London UK	37	7.3	7.7	0.0430	0.0056
London UK - Chicago IL	39	7.8	8.3	0.0475	0.0057
Athens GR - New York NY	41	9.4	9.7	0.0613	0.0063

*** The block hours begin when the aircraft leaves the blocks before takeoff and end when it reaches the blocks after landing.**

† 45-year average effective flight-dose, January 1958 through December 2002.

‡ Column 6 = Column 5 / Column 4

Table 3. Increased Lifetime Risk of Fatal Cancer Because of Occupational Exposure to Ionizing Radiation *

mSv †	Risk	mSv	Risk	mSv	Risk
2	1 in 13000 (0.008%)	20	1 in 1300 (0.08%)	120	1 in 210 (0.5%)
3	1 in 8300 (0.01%)	30	1 in 830 (0.1%)	140	1 in 180 (0.6%)
4	1 in 6300 (0.02%)	40	1 in 630 (0.2%)	160	1 in 160 (0.6%)
5	1 in 5000 (0.02%)	50	1 in 500 (0.2%)	180	1 in 140 (0.7%)
6	1 in 4200 (0.02%)	60	1 in 420 (0.2%)	200	1 in 130 (0.8%)
7	1 in 3600 (0.03%)	70	1 in 360 ‡ (0.3%)	225	1 in 110 (0.9%)
8	1 in 3100 (0.03%)	80	1 in 310 (0.3%)	250	1 in 100 (1.0%)
9	1 in 2800 (0.04%)	90	1 in 280 (0.4%)	275	1 in 91 (1.1%)
10	1 in 2500 (0.04%)	100	1 in 250 (0.4%)	300	1 in 83 (1.2%)

* The risk of fatal cancer in a working-age population (20-64 years) because of occupational radiation exposure is estimated to be 4 in 100,000 per millisievert (0.004% per millisievert) (3).

† mSv is the abbreviation for millisievert(s)

‡ A risk of 1 in 360 from a dose of 70 millisieverts means 1 expected death from radiation-induced cancer for every 360 persons who each received a dose of 70 millisieverts.

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with no more than 50 millisieverts in a single year (3). For a pregnant aircrew member starting when she reports her pregnancy to management, the recommended limit for the conceptus is an equivalent dose of 1 millisievert, with no more than 0.5 millisievert in any month (3).

7. How can an aircrew member find out the effective dose of ionizing radiation received on a flight? If the crewmember is pregnant, how can she find out the equivalent dose of ionizing radiation received by the conceptus?

The computer program CARI-6 calculates the effective dose of galactic cosmic radiation received by a crewmember while flying an approximate great-circle route (the shortest distance) between two airports. Because of the penetrating nature of galactic cosmic radiation, the effective dose received by a pregnant woman is a reliable estimate of the equivalent dose received by the conceptus (3). There is an interactive version of CARI-6 that runs on the Internet and can be reached by a link from the Radiobiology Research Team Web site:

http://www.cami.jccbi.gov/radiation.html

Two versions of the CARI program, CARI-6 and CARI-6M, can be downloaded from the Web site. The downloadable version of CARI-6 is more sophisticated than the interactive version. In addition to calculating a flight dose, the downloadable version also allows the user to store and process multiple flight-profiles and to calculate dose rates at user-specified locations in the atmosphere. CARI-6M does not require a great-circle route between origin and destination airports; it allows the user to specify the flight path by entering the altitude and geographic coordinates of waypoints.

Table 4. Increased Risk of Severe Genetic Defects in First-Generation Offspring Because of Parental Exposure to Ionizing Radiation Prior to the Offspring's Conception *

mSv †	Risk	mSv	Risk	mSv	Risk
10	1 in 25000 ‡ (0.004%)	110	1 in 2300 (0.04%)	210	1 in 1200 (0.08%)
20	1 in 13000 (0.008%)	120	1 in 2100 (0.05%)	220	1 in 1100 (0.09%)
30	1 in 8300 (0.01%)	130	1 in 1900 (0.05%)	230	1 in 1100 (0.09%)
40	1 in 6300 (0.02%)	140	1 in 1800 (0.06%)	240	1 in 1000 (0.1%)
50	1 in 5000 (0.02%)	150	1 in 1700 (0.06%)	250	1 in 1000 (0.1%)
60	1 in 4200 (0.02%)	160	1 in 1600 (0.06%)	260	1 in 960 (0.1%)
70	1 in 3600 (0.03%)	170	1 in 1500 (0.07%)	270	1 in 930 (0.1%)
80	1 in 3100 (0.03%)	180	1 in 1400 (0.07%)	280	1 in 890 (0.1%)
90	1 in 2800 (0.04%)	190	1 in 1300 (0.08%)	290	1 in 860 (0.1%)
100	1 in 2500 (0.04%)	200	1 in 1300 (0.08%)	300	1 in 830 (0.1%)

* The risk of severe genetic defects in first-generation offspring, because of occupational radiation exposure of one or both parents, is estimated to be 4 in 1,000,000 per millisievert (0.0004% per millisievert) (3).

† mSv is the abbreviation for millisievert(s)

‡ A risk of 1 in 25,000 from a dose of 10 millisieverts means 1 child is expected to have 1 or more severe genetic defects for every 25,000 children born to parents who received a combined dose of 10 millisieverts prior to the child's conception.

8. What health concerns for aircrews are associated with their occupational exposure to ionizing radiation?

At the radiation doses received by aircrews, an increased risk of fatal cancer is the principal health concern (3). The following example shows how the increased risk can be estimated. Suppose a crewmember worked 700 block hours per year for 25 years flying between New York, NY, and Chicago, IL (block hours defined in first footnote to Table 2). Based on flight data in Table 2 and assuming the flight dose is the same in both directions, the effective dose of galactic cosmic radiation is 0.0039 millisievert per block hour. In 25 years, the dose to the crewmember would be 68 millisieverts.

25 years x 700 block hours per year x 0.0039 millisievert per block hour = 68 millisieverts

As seen in Table 3, crewmembers receiving 68 millisieverts will, on average, incur an increased lifetime risk of fatal cancer of about 1 in 360 (0.3%). In the general population of the United States in 1998, about 24% of adult deaths were from cancer (3). For an individual, a risk estimate is a rough approximation.

Genetic defects passed on to future generations are a possible consequence of exposure to ionizing radiation (3). A child is at risk of inheriting genetic defects because of radiation received by the parents before the child's conception. Suppose one of the child's parents worked 700 block hours per year for 5 years flying between New York, NY, and Chicago, IL, before the child was conceived. As in the previous example, the effective dose of galactic cosmic radiation received by the parent is assumed to be 0.0039 millisievert per block hour. In 5 years, the dose to the parent would be 14 millisieverts.

Table 5. Increased Lifetime Risk of Fatal Cancer Because of Prenatal Exposure to Ionizing Radiation *

mSv †	Risk	mSv	Risk	mSv	Risk
1.0	1 in 10000 ‡ (0.01%)	1.6	1 in 6300 (0.02%)	4	1 in 2500 (0.04%)
1.1	1 in 9100 (0.01%)	1.7	1 in 5900 (0.02%)	5	1 in 2000 (0.05%)
1.2	1 in 8300 (0.01%)	1.8	1 in 5600 (0.02%)	6	1 in 1700 (0.06%)
1.3	1 in 7700 (0.01%)	1.9	1 in 5300 (0.02%)	7	1 in 1400 (0.07%)
1.4	1 in 7100 (0.01%)	2	1 in 5000 (0.02%)	8	1 in 1300 (0.08%)
1.5	1 in 6700 (0.01%)	3	1 in 3300 (0.03%)	9	1 in 1100 (0.09%)

* The increased lifetime risk of fatal cancer for a child exposed to radiation during prenatal development is estimated to be 1 in 10,000 per millisievert (0.01% per millisievert) (3).

† mSv is the abbreviation for millisievert(s)

‡ A risk of 1 in 10,000 from a dose of 1 millisievert means 1 expected death from radiation-induced cancer for every 10,000 concepti, each of which received a dose of 1 millisievert.

5 years x 700 block hours per year x 0.0039 millisievert per block hour = 14 millisieverts

As seen in Table 4, with a parental dose of 14 millisieverts between 1 in 25,000 (0.004%) and 1 in 13,000 (0.008%) first-generation children would be expected to inherit one or more radiation-induced severe genetic defects. In the general population, 2-3% of liveborn children have one or more severe abnormalities at birth (3).

9. If an aircrew member works during pregnancy, what are the health risks for the child, and how long can the crewmember work before the dose of ionizing radiation to the conceptus exceeds FAA recommended limits?

Even if the dose to the conceptus were as high as 20 millisieverts, no radiation-induced structural abnormalities or mental retardation would be observed (3). However, an increased risk of prenatal death could result from any dose of ionizing radiation during the first day of development (3). The risk would depend on the precise stage of development at the time of irradiation and the radiation dose. If death did occur, the conceptus would most likely be aborted before the pregnancy was recognized. After the first day or two, a dose as high as 20 millisieverts would not affect prenatal survival.

A child irradiated during prenatal development will incur an increased lifetime risk of fatal cancer. Suppose a pregnant crewmember worked 70 block hours each month flying between New York, NY, and Chicago, IL, and the effective dose of galactic cosmic radiation is again assumed to be 0.0039 millisievert per block hour. With galactic cosmic radiation, the effective dose to the pregnant crewmember is a reliable estimate of the equivalent dose to the conceptus (see answer to question 7). Therefore, the estimated monthly equivalent dose to the conceptus is 0.27 millisieverts.

70 block hours per month x 0.0039 millisievert per block hour = 0.27 millisievert

This is well below the recommended monthly limit of 0.5 millisievert (see answer to question 6). The dose to the conceptus would not exceed the recommended pregnancy limit of 1 millisievert as long as the crewmember worked no more than 3.7 months.

1 millisievert / 0.27 millisievert each month = 3.7 months

As seen in Table 5, the increased lifetime risk of fatal cancer from 1 millisievert received during prenatal development is 1 in 10,000 (0.01%). In the general population of the United States (all ages) in 1998, approximately 23% of all deaths were from cancer (3).

Suppose the pregnant crewmember worked on high-altitude, high-latitude, long-distance flights between Athens, GR, and New York, NY. From flight data in Table 2 and assuming the same flight dose in both directions, the effective dose to the pregnant crewmember, and therefore the equivalent dose to the conceptus, would be 0.0063 millisievert per block hour. The pregnant crewmember could work 79 block hours each month without the dose to the conceptus exceeding the recommended monthly limit of 0.5 millisievert.

0.5 millisievert / 0.0063 millisievert per block hour = 79 block hours

The pregnant crewmember could work 2 months without the dose to the conceptus exceeding the recommended pregnancy limit of 1 millisievert.

1 millisievert / 0.5 millisievert each month = 2 months

CONCLUDING REMARKS

Although one cannot exclude the possibility of harm from occupational exposure to radiation at the doses likely to be received during a career of flying, it would be impossible to establish that an abnormality or disease in a particular individual resulted from such exposure.

In estimating radiation-induced health risks for aircrews and their progeny, we used dose-effect relationships recommended by national and international organizations recognized for their expertise in evaluating radiation effects. However, considerable uncertainty exists in the estimates because the original data is primarily from studies on individuals exposed to radiation at much higher doses and dose rates and generally of lower energy than the galactic cosmic radiation to which aircrews are exposed. Also, controls were often inadequate. These differences are the major reason that epidemiological studies involving aircrews are important.

With regard to occupational exposure to radiation during pregnancy, the FAA recommends that a pregnant crewmember and management work together to ensure that exposure of the conceptus not exceed recommended limits.

Under U.S. law, an employer may not limit, classify, or segregate an employee in any way that deprives or tends to deprive him or her of employment opportunities or otherwise affects the status of an employee because of sex or pregnancy.

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